Since the early 1980s, magnetic resonance imaging (MRI) has been the technique of choice for visualizing white matter lesions in the brain. This is especially true for the plaques found in multiple sclerosis (MS). Careful review of scans and the use of pattern recognition are critical for differential diagnosis. Although sensitive to disease, MRI cannot always provide a specific diagnosis. Clinical presentation is then critical for disease differentiation.

Other disease entities can easily be confused on MRI with MS. In MS, periventricular changes are typically punctate and asymmetric in distribution (from side to side). Postmortem studies have confirmed that the white matter abnormalities demonstrated by MRI correspond to MS plaques. Edema associated with acute lesions and gliosis with chronic lesions permit visualization. Demyelination by itself does not contribute significantly to alterations in proton density or relaxation, and thus is not directly visualized with conventional imaging techniques. In chronic small vessel ischemic disease, which can mimic MS, periventricular changes are often milder and smoother in contour. However, the white matter changes found in some patients closely resemble those of advanced MS.

In very ill, uncooperative patients with intracranial infection, computed tomography (CT) can be superior to MRI because of its shorter imaging times. However, MRI offers the advantage of direct, high-resolution, multiplanar imaging with superior sensitivity to inflammatory change. In a mature abscess, the capsule can often be differentiated from inner debris and surrounding edema on unenhanced MRI. CT offers advantages in detecting calcifications, such as those associated with chronic infections (e.g., cysticercosis) and end-stage congenital infection. However, MRI is more sensitive to parenchymal hemorrhage regardless of stage. MRI can detect hemorrhage long after CT scans become normal, allowing more complete characterization of certain infectious diseases. With meningeal disease, enhanced MRI is more sensitive than enhanced CT. In the encephalitides (e.g., herpes simplex type 1), MRI can also reveal widespread abnormalities simply not seen on CT.

MRI is favored in almost all instances over CT for the evaluation of patients with suspected white matter disease or intracranial infection. CT should be considered only if the detection of calcifications is important for diagnosis. MRI’s strength lies in its superior demonstration of soft tissue abnormality because of its ability to gauge tissue water. In common with CT, differential diagnosis is largely based on the pattern of disease involvement.

WHITE MATTER DISEASE
Multiple Sclerosis

MS is characterized clinically by multiple neurologic episodes separated in time. Two thirds of patients are female. The disease progresses in a relentless stepwise fashion, marked by exacerbations and remissions. MS is highly variable in its course. A study from the Mayo Clinic documented that 75% of patients were alive 25 years after onset, 55% without significant disability. McAlpine’s scale, based on clinical criteria, defines definite MS as that with characteristic transient neurologic symptoms and one or more documented relapses. Probable MS is defined as that with one or more attacks of disease and clinical evidence in the first attack of multiple lesions. Possible MS is defined as that with a similar history to probable disease but with a paucity of findings or unusual features. Dictation of films should avoid use of this terminology (definite, probable, or possible MS), a standard in the practice of neurology and based on clinical criteria alone. MRI is extremely sensitive for the detection of MS plaques in the brain and spinal cord. However, clinical assessment continues to be crucial for appropriate diagnosis.

The diagnosis of MS by MRI hinges on pattern recognition. Most lesions are small, 1 to 5 mm in diameter. The most common location of MS plaques is in the periventricular region, particularly adjacent to the superolateral angles of the lateral ventricles (Fig. 4–1). There is often a marked asymmetry in lesion distribution (comparing lesions in the right and left hemispheres), a factor distinguishing it from ischemic disease, which is often encountered in the elderly patient. Other common locations for lesions include the centrum semiovale, atrial trigone, occipital horns, forceps major and minor, colliculi, and temporal horns (Fig. 4–2). Approximately 30% of patients demonstrate brainstem and cerebellar lesions; the middle cerebellar peduncles are a preferred location. Corpus callosum involvement by MS is common (Fig. 4–3). Thirty percent of patients demonstrate focal lesions in this location, a percentage established both by imaging studies and pathologic exam. Callosal lesions with a flat border along the ependymal surface of the ventricles and otherwise a round or oval shape are relatively specific for MS. These are best visualized on sagittal images. Focal or diffuse atrophy of
FIGURE 4–1. Multiple sclerosis (characteristic lesion locations). T2-weighted scans from two patients, one man and one woman, both 38 years old, are presented. Each patient had intermittent weakness and numbness of the upper and lower extremities as well as problems with balance. Multiple punctate high-signal-intensity lesions are noted, located predominantly in the white matter. Lesions can be identified in the medulla (A), in the pons and middle cerebellar peduncle (B), adjacent to the temporal horn (C, arrow), and in the white matter immediately adjacent to the lateral ventricles (D and E). Only the periventricular and supraventricular lesions were clearly seen on the T1-weighted images (not shown). In both patients, there was no abnormal enhancement noted on the postcontrast exam (not shown).

the corpus callosum is seen in 40% of patients. Thinning of the corpus callosum results from general cerebral atrophy and accompanying wallerian degeneration. Changes in the corpus callosum are most prominent in patients with long-standing and extensive disease. Although MS is commonly thought of as a white matter disease, 5% to 10% of plaques occur in gray matter. These can be seen in the cortex and in the basal ganglia. There are many pitfalls in the MRI diagnosis of MS. Differentiation from other clinical entities that mimic MS on MRI depends on pattern recognition and correlation with clinical history.

Fast spin echo scans with moderate T2-weighting and fluid-attenuated inversion recovery (FLAIR) scans with heavy T2-weighting are preferred for visualization of MS plaques in the brain. Both techniques depict lesions as high-signal-intensity foci, contrasting well against a background of intermediate to low-signal-intensity brain and cerebrospinal fluid (CSF). Conventional heavily T1-weighted scans should not be used. These fail to detect some MS lesions because of their proximity to high-signal-intensity CSF. The primary plane for imaging is axial. This choice is often supplemented by T2-weighted scans in the sagittal and coronal planes. The use of thin sections, 5 mm or less, is critical for lesion detection, minimizing partial volume effects.

MS plaques are characterized by prolonged T1 and T2 relaxation times and increased proton density. MS plaques are low signal intensity on T1-weighted scans and high signal intensity on T2-weighted scans. T1-weighted scans are poor for lesion visualization, unless heavily T1-weighted FLAIR scans are used. Even with these, only lesions entirely circumscribed by normal white matter are well seen. T2-weighted scans, regardless of technique, are insensitive to lesions adjacent to the ventricles or gray matter, because of the lack of contrast with these structures. T2-weighted scans, which depict plaques as high signal intensity foci compared with adjacent normal brain, are preferred for lesion detection. For visualization of brainstem and cerebellar lesions, compensation by software techniques (such as gradient moment nulling) for CSF motion is important. MRI is markedly more sensitive than CT for detection of lesions, regardless of location. CT detects only larger
FIGURE 4–2. Multiple sclerosis (other characteristic lesion locations and imaging appearances). T2-weighted scans are shown from a 32-year-old white woman with a 10-year history of disability. The patient initially presented with fatigue and unsteadiness. Clinical exacerbation of disease led to two previous hospital admissions. Ataxia of all extremities was noted 3 years before the current admission; the patient became wheelchair bound 1 year later. The patient now presents with increasing numbness of the extremities and urinary incontinence. However, neurologic exam does not reveal evidence of a new focal brain lesion. Lesions (which are predominantly punctate in configuration) are noted in the right cerebellar hemisphere (A), in the left pons and superior colliculus (B), and immediately adjacent to the lateral ventricles (C), with asymmetry of disease involvement when comparing the right and left hemispheres. Because of the large number of plaques immediately adjacent to the lateral ventricles, the disease appears somewhat confluent in this region. Other scans (not shown) revealed mild diffuse cortical atrophy and thinning of the corpus callosum. No abnormal enhancement was noted on postcontrast T1-weighted scans (not shown).

FIGURE 4–3. Multiple sclerosis (involvement of the corpus callosum). T2-weighted scans are shown from an 18-year-old woman with new onset of left lower extremity paresthesia, which progressed to include the left upper extremity. A few days later, abnormal sensation developed in the right lower extremity. A and B, At the level of the lateral ventricles, at least four periventricular lesions (white arrows) are seen. The lesions lie medial to the lateral ventricle and thus lie within the corpus callosum. On a sagittal scan with intermediate T2-weighting (C), the larger of the callosal lesions is well seen (black arrow). On the postcontrast exam (not shown), several other larger lesions were noted to enhance along with a cord lesion at C2.
lesions. Less severe disease is undetected by CT, with the scan appearing normal.

Acute MS lesions tend to be large, greater than 1 cm, with indistinct margins. Well-demarcated, small punctate lesions are much more common, and for the most part correspond to chronic (quiescent) disease. Lesions larger than 1 cm can represent confluent plaques of different ages or clinically active disease. Both acute and chronic lesions have high signal intensity on T2-weighted scans. In acute disease, this corresponds to edema. In chronic disease, this corresponds to gliosis. Demyelination per se does not contribute significantly to the change in relaxation time.

MS plaques are also not necessarily homogeneous in appearance. The border of a lesion can, on occasion, be differentiated from the center on precontrast scans, an appearance more common with acute plaques. A thin line of moderately high signal intensity (T1 shortening) can be seen at the edge of some MS lesions on T2-weighted images. Postcontrast, this line corresponds to the edge of the enhancing region. On tissue pathology, an accumulation of myelin breakdown products is found in this region at the edge of active lesions.

The vast majority of MS plaques remain unchanged on follow-up MR scans. However, new lesions are often observed with the apparent resolution of older lesions. Confluent abnormalities in the periventricular region correlate with long-standing disease. Periventricular disease, when severe, has a characteristic irregular, “lumpy-bumpy” outer margin. This feature can be useful to distinguish MS from small vessel ischemic disease. The latter typically has a smooth outer margin in the immediate periventricular region. Involvement of the periventricular white matter in MS is also often markedly asymmetric, when the left hemisphere is compared with the right.

MRI is commonly used to assess disease activity and the effectiveness of medical therapy. Patients with more severe disease have a larger number of plaques and more confluent white matter disease. Thinning of the corpus callosum and generalized parenchymal atrophy are also seen in long-standing disease. Many of the lesions depicted by MRI are clinically silent. Consequently, MRI is more sensitive for detecting disease and demonstrating disease activity than physical examination. Studies with experimental allergic encephalomyelitis (EAE), an animal model of demyelinating disease, have advanced substantially our knowledge of imaging-pathologic correlation.

With regard to contrast administration, it is the minority of patients with MS who demonstrate enhancing lesions. The majority of lesions visualized on MRI are chronic in nature and thus do not enhance. Results from clinical trials reveal that contrast enhancement is more sensitive than clinical exam in detecting active disease. Enhancement after contrast administration is a consistent finding in new lesions. MS is a dynamic disease; lesions demonstrate dramatic changes during longitudinal study. Lesion enhancement is best seen on scans obtained within 5 to 10 minutes after contrast injection. Lesion enhancement is transient, persisting for fewer than 4 weeks in most cases. Some lesions demonstrate punctate enhancement (Fig. 4–4) and others ring enhancement (Fig. 4–5). Evolution in appearance, over days to weeks, from punctate to ring-like enhancement, has also been observed. Serial scans reveal some lesions reverting to normal signal intensity on T2-weighted images, suggesting resolution of transient inflammatory changes.

MS plaques can also be visualized in the cervical and thoracic spinal cord. These lesions often do not respect gray-white matter boundaries, nor do they follow specific fiber tracks. Lesions are often elongated, paralleling the axis of the cord, and are more common dorsally and
FIGURE 4-5. Multiple sclerosis (MS) mimicking metastatic disease. On the sagittal heavily T₂-weighted fast spin echo scan (A), multiple periventricular high-signal-intensity abnormalities are noted. Some involve the corpus callosum and have a broad base along the border of the lateral ventricle. The distribution of the lesions in the periventricular white matter is confirmed on the axial scan with intermediate T₂-weighting (B). On the corresponding postcontrast T₁-weighted scan (C), many of the lesions demonstrate ring enhancement. Focusing on the postcontrast exam alone, the multiplicity of lesions and ring enhancement could lead to an incorrect diagnosis of metastatic disease. The knowledge that MS plaques can demonstrate ring enhancement, together with recognition of the characteristic location of these lesions, leads to the proper diagnosis. The availability of pertinent clinical history is also paramount to film interpretation.

Laterally within the cord. Before the advent of MRI, spinal cord lesions were rarely demonstrated radiologically. Cervical lesions are detected more commonly by MRI than thoracic lesions, a finding that may be related to technique. Imaging of the thoracic cord is still inferior to that of the cervical cord because of differences in coil design and problems caused by respiratory and cardiac motion. T₂-weighted imaging in both the sagittal and axial planes is recommended to confirm the presence of lesions. Although lesions can be demonstrated in the cervical and thoracic cord, brain MRI is advocated (in addition to spine imaging) for the evaluation of patients with primarily spinal cord symptoms. As an imaging modality, MRI is more sensitive for the detection of brain lesions in MS than spinal cord lesions. Furthermore, the demonstration of characteristic periventricular plaques can confirm the diagnosis of MS, whereas spinal imaging may reveal only one or two nonspecific lesions.

Optic Neuritis

For the study of patients with optic neuritis, both a screening examination of the brain and an examination focusing on the optic nerves are recommended. The actual demonstration of optic nerve lesions can be difficult, demanding attention to imaging technique. With good technique, optic nerve lesions are seen in more than 90% of symptomatic patients. However, visual evoked potentials remain more sensitive for isolated optic nerve lesions. Disseminated areas of demyelination in the brain can also be observed in patients with optic neuritis in a pattern similar to MS. The frequency with which patients with isolated optic neuritis subsequently acquire MS remains controversial.

The use of fat suppression is particularly important for the study of the optic nerves. Surrounding orbital fat impedes recognition of optic nerve lesions because of chemical-shift artifact and loss of lesion contrast. T₂-weighted scans with fat suppression reveal nerve enlargement and edema. Postcontrast T₁-weighted scans with fat suppression show abnormal contrast enhancement of the nerve.

Small Vessel Ischemic Disease

Patchy white matter lesions, or small vessel ischemic disease (see Chapter 3), common in elderly patients and those with cerebrovascular disease, must be differentiated on MRI from MS. The lesions can be periventricular in location or situated more peripherally (Fig. 4–6). Involvement in the two hemispheres is usually relatively symmetric (Fig. 4–7). This is different from MS, in which involvement is often markedly asymmetric. When periventricular in location, the exterior margin of the involved region is often relatively smooth, providing another key for differentiation from MS.

Twenty percent to 30% of elderly patients in good general medical health demonstrate patchy white matter lesions on brain MRI. These correspond on postmortem study to areas of gliosis and demyelination, presumably caused by chronic vascular insufficiency. Larger lesions may demonstrate necrosis, axonal loss, and demyelination, thereby representing true infarcts. These lesions and those of frank infarction account for the majority of focal white matter lesions seen on MRI in the elderly population. CT commonly fails to reveal these abnormalities. The patchy white matter lesions seen in the elderly population should be distinguished from focal gliosis and encephalomalacia surrounding ventricular shunts.

In most patients, some degree of periventricular hyperintensity can be recognized on MRI. A fine line of
**FIGURE 4–6.** Small vessel ischemic disease with predominantly punctate lesions. The patient is a 72-year-old man with multiple medical problems. Numerous foci of increased signal intensity are present in the white matter (primarily the subcortical white matter, a distinguishing factor from multiple sclerosis) on the first (A) and second (B) echoes of the axial T2-weighted scan. The lesions are not clearly seen on the axial T1-weighted scan (C). Note the poor gray-white matter contrast on both the T1- and T2-weighted images. There was no abnormal contrast enhancement (not shown).

**FIGURE 4–7.** Small vessel ischemic disease, a mixture of punctate, and less well-defined white matter lesions. Multiple foci of abnormal high signal intensity are noted on the T2-weighted scan (A) in the subcortical and periventricular white matter. The abnormal areas correspond pathologically to necrosis, infarction, demyelination, and astroglial proliferation. The lesions adjacent to cerebrospinal fluid are better seen on the fluid-attenuated inversion recovery scan (B). Note that the involvement is very symmetric, from side to side, one distinction from the typical imaging presentation with multiple sclerosis. The lesions are poorly visualized on the T1-weighted scan (C) and do not demonstrate enhancement on the postcontrast scan (D).
FIGURE 4–8. Transependymal cerebrospinal fluid (CSF) flow. There is dilatation of the lateral ventricles on the intermediate (A) and heavily (B) T₂-weighted scans. The patient is a 5-year-old girl who received radiation therapy for a brainstem glioma (not shown). A thick, smooth rim of periventricular white matter hyperintensity is identified surrounding the lateral ventricles, best seen on the scan with intermediate T₂-weighting (A). This involves only the periventricular white matter and does not extend into the basal ganglia. Ventricular size and periventricular signal intensity were normal on the axial T₂-weighted scan (C) performed 45 days earlier. At that time, there was no obstruction to CSF flow. The brainstem lesion subsequently hemorrhaged, enlarging and obstructing CSF outflow.

high signal intensity adjacent to the ventricular system, often more prominent surrounding the frontal horns, should be considered a normal finding and not indicative of demyelinating disease or hydrocephalus. This pattern must be distinguished from that seen with transependymal flow in obstructive hydrocephalus (Fig. 4–8).

Systemic Lupus Erythematosus

As with most other injuries to the brain, MRI demonstrates high sensitivity to the lesions of systemic lupus erythematosus (SLE) (see also Chapter 3). Patients with SLE demonstrate a broad range of disease involvement, from perivascular microinfarctions to discrete cerebral infarction. Partial or complete resolution of gray matter lesions can be seen on follow-up exams. The wedge shape of lesions in many patients and involvement of both gray and white matter assist in differentiation from MS. MRI is an important modality for detecting the extent of cerebral injury in SLE; CT is much less sensitive.

Hypoxemic Injury

Hypoxemic (subnormal oxygenation of arterial blood) injury (see also Chapter 3) to the brain can be the result of decreased concentration of functional hemoglobin (anemic hypoxia), hypoperfusion (ischemic hypoxia), or defective oxygenation (hypoxic hypoxia). Causes include carbon monoxide poisoning, cardiorespiratory arrest (Fig. 4–9), and near-drowning. All can produce irreversible brain damage. The white matter diseases discussed

FIGURE 4–9. Hypoxemic injury (infarction). A, Abnormal high signal intensity is noted bilaterally on the T₂-weighted scan in the putamen, globus pallidus, and caudate nuclei. There is also patchy increased signal intensity in cortical gray matter. This is most prominent on the patient’s left side, in the watershed regions between the anterior and middle cerebral artery territories, and between the middle and posterior cerebral artery territories. Findings are similar, but less evident, with abnormal low signal intensity on the T₁-weighted scan (B). The patient presented for imaging several days after respiratory arrest.
Periventricular Leukomalacia

Periventricular leukomalacia (PVL) is the result of white matter hypoperfusion in watershed areas in the premature infant, which progresses to infarction. Clinical sequelae include spastic diplegia, quadriplegia, cerebral palsy, and mental retardation (in severe cases). MRI is often performed in the young child, visualizing chronic end-stage changes. These include decreased quantity of periventricular white matter and abnormal increased signal intensity (on T2-weighted images) in the adjacent white matter (see Chapter 3, Fig. 3–37). The latter corresponds to gliosis. The areas most commonly affected include the white matter adjacent to the atrial trigone and frontal horn. Focal or generalized ventricular enlargement can be seen as a result of ex vacuo dilatation. There may also be thinning of the corpus callosum. Although neurosonography is used for evaluation of the neonate, the sensitivity of this modality is low in mild or moderate disease. Follow-up MRI in symptomatic infants can confirm the diagnosis of PVL despite a negative neonatal ultrasound examination. The pattern of white matter involvement in PVL in the young child can resemble that of small vessel ischemic disease in the elderly. Age and clinical history clearly differentiate these two populations.

Radiation Injury

Symmetric periventricular white matter hyperintensity on T2-weighted scans is a typical finding in radiation injury to the brain (Fig. 4–12). MRI evidence of injury is more likely to be seen in older patients, in cases involving higher radiation dose (and larger volume of radiated tissue), and when radiation is combined with chemotherapy. The injury to white matter by radiation consists of demyelination, edema, and fibrillary gliosis. The pattern may be focal, if radiation is restricted to a port, or diffuse. In diffuse disease, involvement of the white matter may extend to the interface with cortical gray matter. The scalloped appearance of radiation in-

Toxic Demyelination

Of the demyelinating diseases resulting from problems with nutrition or metabolites (with the exception of inborn errors of metabolism), central pontine myelolysis (CPM) and Wernicke’s encephalopathy are two that demonstrate characteristic findings on MRI. In CPM, there is symmetric destruction of myelin sheaths, which appears to start from the median raphe of the pons. The lesion can involve part of or the entire base of the pons. Contiguous spread into the dorsal pons (tegmentum) and superiorly into the mesencephalon (midbrain) has been reported. The cause is believed to be an osmotic injury secondary to rapid correction of severe chronic hyponatremia (see Chapter 3 for a further description). In Wernicke’s encephalopathy, there is involvement of the periventricular structures at the level of the third and fourth ventricles. Patients with classic Wernicke’s encephalopathy exhibit confusion, nystagmus (less commonly ophthalmoplegia), and truncal ataxia. These clinical findings reflect the localization of the lesions pathologically. MRI reveals lesions in these characteristic locations (Fig. 4–11). Untreated, Wernicke’s encephalopathy is a progressive disease. The administration of thiamine reverses the disease over the course of days to weeks, although mortality even with treatment is 10% to 20%.
FIGURE 4–11. Wernicke's encephalopathy. T1-weighted scans pre- (A) and postcontrast (B) are shown. Magnetic resonance findings include symmetric periventricular lesions that are hyperintense on T2-weighted scans and enhanced after contrast administration (in the acute phase) on T1-weighted scans. Bilateral involvement of the mammillary bodies, as seen in this case with enhancement postcontrast (arrows), is characteristic. This uncommon disorder is caused by thiamine deficiency. Clinical diagnosis is difficult; the disease is characterized by ophthalmoplegia, ataxia, and disturbances of consciousness. These clinical signs may or may not be present. Wernicke’s encephalopathy is due to malnutrition or malabsorption (often after prolonged alcohol intake).

FIGURE 4–12. White matter changes as a result of therapeutic radiation. A and B, There is diffuse symmetric white matter hyperintensity on the T2-weighted scans. The involvement extends to the cortical gray matter and is scalloped laterally. The corpus callosum is spared. The white matter changes are typically accompanied by cortical atrophy, also present in this case. C and D, The atrophy is clearly seen on T1-weighted scans; the diffuse abnormality of white matter is less evident. Another typical finding is loss of gray-white matter differentiation, which is also present in this case.
jury at the gray-white matter junction represents extensive white matter damage involving the more peripheral arcuate fibers. This pattern can be differentiated from transependymal absorption, which does not extend to the gray-white matter junction and demonstrates a sharp, rounded margin. The corpus callosum is usually spared in radiation injury. Diffuse white matter disease can also be caused by inhalation of organic solvents. However, uniform involvement of both central and peripheral white matter is more characteristic of radiation injury. Radiation-induced changes can mask recurrent tumors and other pathologic findings. MRI demonstrates high sensitivity to radiation-induced changes but low specificity. CT is relatively insensitive for detecting radiation damage; visualization of abnormalities is confined primarily to patients with severe disease. Both MRI and CT demonstrate the late sequelae of radiation therapy, which include sulci enlargement and ventriculomegaly. Abnormal contrast enhancement is seen in areas of radiation necrosis (Fig. 4–13). MRI, like CT, lacks specificity in discriminating recurrent tumor from radiation necrosis (using conventional imaging sequences). Both are seen as focal enhancing lesions with surrounding edema. First-pass studies, acquired during bolus intravenous contrast injection, do, however, permit differentiation of these two entities. Classically, radiation necrosis demonstrates very low cerebral blood volume (CBV), whereas recurrent tumor manifests high CBV.

**Dilated Perivascular Spaces**

Dilated perivascular spaces (see also Chapter 3) are a normal finding on MRI. They occur in three common locations. The perivascular space is an invagination of the subarachnoid space. Also known as the Virchow-Robin space, it surrounds perforating arteries entering the brain and contains CSF. The most common location for a dilated perivascular space is within the inferior one third of the basal ganglia adjacent to the anterior commissure and following the course of the lenticulostriate arteries. In this location, they are usually smaller than 5 mm in diameter but can be larger. Another common location is within the high convexity white matter of the centrum semiovale following the course of nutrient arteries (Fig. 4–14). Lesions in this location are usually less than 2 mm in diameter. A third common location is the midbrain, at the junction of substantia nigra and cerebral peduncle following the branches of collicular arteries (Fig. 4–15). In this location, they are usually less than 1.5 mm in diameter. Dilated perivascular spaces are commonly noted on MRI but rarely visualized on CT.

It is important to distinguish this common variant from other pathologic entities, such as lacunar infarction, that carry more serious clinical implications. Dilated perivascular spaces are isointense compared with CSF on all pulse sequences. Except for cavitated old lesions, lacunar infarcts do not have CSF signal intensity on all scans and are hyperintense to CSF on intermediate T₁-weighting. In general, dilated perivascular spaces are smaller than lacunar infarcts. The latter are often more slitlike and in the basal ganglia occur in the superior two thirds (as opposed to the inferior one third).

**INFECTION**

Infection may reach the intracranial contents by hematogenous spread, direct extension (e.g., from sinusitis), and spread along peripheral nerves (e.g., herpes enceph-
FIGURE 4–14. Supraventricular dilated perivascular spaces. T2-weighted fast spin echo (A) and (B) fluid-attenuated inversion recovery scans, together with T1-weighted pre- (C) and postcontrast (D) scans reveal multiple small punctate cerebrospinal fluid signal intensity lesions in the supraventricular white matter.

FIGURE 4–15. Dilated perivascular spaces (DPVSs) in the midbrain. Although described later in the literature than DPVSs in the basal ganglia and high convexity white matter, this normal variant is also not uncommon in the midbrain. Here, the location is very specific: at the junction of the substantia nigra and the cerebral peduncle. DPVS may be unilateral or bilateral, as in this case (arrows). The signal intensity is that of cerebrospinal fluid, as shown on fast spin echo T2-weighted (A), fluid-attenuated inversion recovery (B), and precontrast (C) T1-weighted scans.
alitis). MRI is extremely valuable for early detection of parenchymal disease. Dystrophic calcification, which represents the primary finding on CT in chronic and congenital infection, is poorly visualized.

**Parenchymal Disease**

*Staphylococcus, Streptococcus,* and more recently *Toxoplasmosis* (in AIDS) are the common organisms responsible for focal parenchymal brain infections. The temporal evolution of brain infection has been carefully studied on both CT and MRI. An abscess evolves from an early focus of cerebritis to a more mature stage with a discrete capsule. Abnormal contrast enhancement occurs as a result of blood-brain barrier disruption (Fig. 4–16). Contrast enhancement on MRI permits early lesion identification (with sensitivity superior to that of unenhanced MRI and enhanced CT) and differentiation of cerebritis and capsule stages. Cerebritis demonstrates focal enhancement, often ill defined, while the capsule stage demonstrates ring enhancement (Figs. 4–17 and 4–18). Enhanced MRI also provides more precise delineation of disease extension. The evolution of intracranial infection, whether treated by antibiotic therapy or neurosurgical drainage, is well evaluated by MRI.

Incidental sinus disease is commonly seen on MRI. The spectrum of disease includes retention cysts and mucosal inflammation. Much less common is active infection. Intracranial complications from sinus infection include meningitis, abscess, and sinus thrombosis. The presence of a true air-fluid level within the sinus, opacification of the sinus by soft tissue with intermediate signal intensity on T2-weighted scans, and prominent abnormal contrast enhancement (Fig. 4–19), given the appropriate clinical presentation, point toward acute sinus infection.
**FIGURE 4–18.** Neurocysticercosis. On the precontrast T₂-weighted scan (A), an ovoid area of abnormal high signal intensity is noted in the region of the sylvian fissure. On the T₁-weighted scan after contrast administration (B), there is ring enhancement of the lesion, with a suggestion of septations. In neurocysticercosis (infection by the larval stage of the pork tapeworm), the patient may present with either seizures, because of parenchymal cysts, or obstructive hydrocephalus, because of intraventricular cysts. On magnetic resonance imaging, the cysts have fluid signal intensity, with ring enhancement postcontrast of the cyst wall.

**FIGURE 4–19.** Mastoiditis, with transverse and sigmoid sinus thrombosis. The patient is a 7-year-old boy with right earache, nausea, vomiting, and low-grade fever. Physical exam revealed a right sixth nerve palsy and a very erythematous right tympanic membrane. On the precontrast T₁-weighted scan (A), there is abnormal mixed signal intensity in the right mastoid air cells and petrous bone. Note that this abnormal soft tissue does not have high signal intensity, which is a common finding as a result of inflammation (but without active infection). The presence of abnormal soft tissue is confirmed on the precontrast T₁-weighted scan (B); the postcontrast scan (C) reveals prominent enhancement (white arrow). The sigmoid sinus remains at low signal intensity on all scans, suggesting occlusion. On a follow-up precontrast T₁-weighted scan obtained 10 days later (D), there is abnormal hyperintensity (black arrow) in the right transverse sinus consistent with evolution of thrombus (in the transverse sinus) from deoxyhemoglobin to methemoglobin. Repeat exam 1 month later demonstrated recanalization of the sinus (scans not shown).
The most common cause of diffuse parenchymal infection is viral. The brain responds to insult with an inflammatory infiltration of lymphocytes and mononuclear cells. Petechial hemorrhage can result from vascular necrosis. Herpes simplex type 1 encephalitis typically involves the temporal lobe, although involvement may extend to the frontal or parietal lobes (Fig. 4–20). The basal ganglia are usually spared. MRI allows early diagnosis and can document effective response to therapy. Coronal imaging is useful for improved visualization of temporal lobe disease in this and other diseases. Herpes simplex type 2 encephalitis can occur in the infant exposed at birth during vaginal delivery. Infection in the infant causes a widespread necrotizing meningoencephalitis. Early in the disease course, brain edema may be patchy or widespread. Areas of involvement increase rapidly in size. Late findings include cortical atrophy and multicystic encephalomalacia. On CT, punctate or gyral calcification can also be seen at this stage.

Acute disseminated encephalomyelitis is an inflammatory and demyelinating disorder of white matter, which can occur after a childhood viral infection. CT is usually nondiagnostic. MRI demonstrates multiple foci of demyelination in the brainstem, cerebellum, and cerebrum (Fig. 4–21). Lesions are relatively few and nonhemorrhagic, with asymmetric involvement of the left and right hemispheres. Follow-up MRI exams can demonstrate resolution of lesions in conjunction with clinical improvement. MRI is an important modality for diagnosing acute disseminated encephalomyelitis because of its ability to identify the sites and extent of involvement and response to therapy.

Two main patterns of brain involvement occur with sarcoidosis. Parenchymal disease presents with symptoms of an intracranial mass lesion. Periventricular and more peripheral white matter lesions can be seen. This pattern in certain instances is indistinguishable from that of MS. The parenchymal lesion, granulomatous in
nature, is the result of disease spread via the Virchow-Robin spaces. Parenchymal involvement is typically accompanied by leptomeningitis. Meningeal disease can present with cranial nerve palsies, meningeal signs, and hypothalamic dysfunction. The granulomatous leptomeningitis seen in sarcoidosis involves the skull base and can be either focal or diffuse (Fig. 4–22). As with other brain infections, MRI is more sensitive than CT and better demonstrates the extent of disease.

**Meningeal Disease**

Contrast-enhanced MRI is markedly superior to CT for the detection of meningeal disease. Unfortunately, neoplastic, inflammatory, and traumatic changes often cannot be differentiated. Contrast-enhanced MRI is also more effective than CT in the identification of complications of meningitis, including ventriculitis and cerebritis. Abnormal areas of contrast enhancement correlate pathologically with inflammatory cell infiltration (Fig. 4–23). Pathology studies also reveal that inflammation can extend beyond the region identified by abnormal contrast enhancement.

Dural enhancement is common after intracranial surgery (Fig. 4–24). Head trauma is also recognized as a cause of dural enhancement. Once present, dural enhancement can persist indefinitely. Abnormal enhancement is likely the result of a chemical arachnoiditis caused by blood. Involvement of the pia-arachnoid (with or without dural involvement) (Fig. 4–25), indicative of acute meningitis, should be distinguished from involvement of the dura alone, the latter commonly chronic in nature.

MRI is also superior to CT for detecting extracerebral

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**FIGURE 4–22. Neurosarcoidosis.** A, The T2-weighted scan appears to be normal. On the postcontrast T1-weighted scan (B), there is diffuse enhancement of the leptomeninges. On imaging, two major patterns of brain involvement are seen with neurosarcoidosis: (1) granulomatous leptomeningitis and (2) parenchymal involvement because of spread along the Virchow-Robin spaces.

**FIGURE 4–23. Viral meningitis.** A, The T2-weighted scan is grossly normal, with the exception of ventricular dilatation. On the precontrast T1-weighted scan (B), the gray matter immediately adjacent to cortical sulci appears to have too low signal intensity. That the cortical gray matter is diffusely edematous is indirectly confirmed by the postcontrast T1-weighted scan (C), which demonstrates diffuse abnormal leptomeningeal enhancement. The imaging appearance of viral meningitis, with diffuse enhancement of the pia arachnoid, is indistinguishable from that of bacterial meningitis.
FIGURE 4–24. Postsurgical dural enhancement. Comparison of precontrast T₂- (A) and T₁-weighted (B) scans with postcontrast axial (C) and coronal (D) T₁-weighted scans reveals diffuse intense dural enhancement. Identification of a ventricular shunt (arrow) on the coronal scan (D) suggests the cause: recent surgery. Dural enhancement, once present, is likely to remain for life. Although typically representative of chronic disease, it can be seen in acute settings and with active infection.

FIGURE 4–25. Bacterial meningitis (postoperative). A, On the T₂-weighted scan, edema in the pons, middle cerebellar peduncle, and cerebellar hemisphere is noted. Postoperative changes are present, including fat packing. The latter is best seen on the precontrast T₁-weighted scan (B). The patient is in the early postoperative period after resection of a large acoustic neuroma. There is mass effect on the brainstem and fourth ventricle. C, On the postcontrast T₁-weighted scan, there is intense enhancement of the dura, in particular at the site of recent surgery. Mild cases of meningitis may show no abnormality on magnetic resonance scans. Severe disease will display marked enhancement of the coverings of the brain.
BRAIN: WHITE MATTER DISEASE AND INFECTION

FIGURE 4–26. Bilateral subdural hematomas. On the T₁-weighted scan, high-signal-intensity extra-axial fluid collections are noted bilaterally. On the T₂-weighted scan (not shown), the collection on the right was also high signal intensity, but the collection on the left was low signal intensity. This indicated that the subdurals were of different ages: the one on the right was made up of extracellular methemoglobin and that on the left, intracellular methemoglobin.

fluid collections (Fig. 4–26). Epidural and subdural hematomas appear smaller on CT as a result of Hounsfield artifact. Contrast-enhanced MRI plays an important role in the diagnosis and follow-up of subdural and epidural empyemas (Fig. 4–27). Early diagnosis is critical with subdural empyemas because of the possible sequelae of cortical venous thrombosis and infarction. If all pulse sequences are compared, purulent fluid can be distinguished from CSF because of the shortening of T₁ and T₂. Contrast enhancement is marked, consistent with infection. Epidural empyemas can be caused by the extension of sinus or ear disease or can occur as a complication after neurosurgical intervention.

AIDS

Greater sensitivity to disease involvement makes MRI superior to CT for the examination of patients with AIDS and its central nervous system complications. White matter lesions are clearly visualized on T₂-weighted scans. Contrast enhancement is important for biopsy localization, judging lesion activity, and detecting small cortical lesions with minimal surrounding edema.

Diffuse periventricular hyperintensity on T₁-weighted scans is common in HIV encephalitis (Fig. 4–28). These changes are a result of a direct neurotrophic effect of the virus. Cortical atrophy and ventricular enlargement are found in virtually all patients with HIV encephalitis (Fig. 4–29), reflecting chronic infection and prolonged debilitation.

Toxoplasmosis is a ubiquitous obligate intracellular protozoan. Approximately 50% of the U.S. population have been exposed and have antibodies. Transmission is through insufficiently cooked meat and handling of cat feces. Toxoplasmosis is an important pathogen in the fetus and the immunocompromised patient. Transmission to the fetus occurs during acute infection of the mother.

FIGURE 4–27. Epidural abscess (empyema), with accompanying osteomyelitis. A 24-year-old patient presented with progressive right-sided headache, fever, and vomiting for 3 weeks. Blood cultures were positive for Salmonella. Abnormal high signal intensity, representing subcutaneous soft tissue edema, is seen on the T₁-weighted scan (A) in the right frontal region. There is also a subtle abnormal increase in signal intensity of the adjacent diploic space (between the inner and outer tables of the skull). The presence of an extra-axial mass, together with involvement of the adjacent marrow, is confirmed by enhancement (white arrow) on the postcontrast T₁-weighted scan (B). The disease involvement is better demonstrated by comparison of the pre- (C) and postcontrast (D) coronal scans. C. Note the hypointense rim, corresponding to the dura (black arrow), separating the lesion from normal brain.
FIGURE 4–28. HIV encephalitis. A man in his 40s presented with dementia and was found to be HIV positive. On the T2-weighted scans, there is diffuse increased abnormal high signal intensity in the white matter bilaterally. Diffuse periventricular white matter hyperintensity, on T2-weighted scans, is a hallmark of HIV encephalitis.

FIGURE 4–29. HIV encephalitis. A 33-year-old HIV-positive man with a CD4 count of 36 presented with progressive mental confusion over the past several years. A, The T2-weighted scan demonstrates diffuse abnormal high signal intensity in the periventricular white matter. B, The T1-weighted scan demonstrates central and peripheral (cortical) atrophy. There is also loss of the normal differentiation between gray and white matter (on the basis of signal intensity). There was no abnormal contrast enhancement (not shown). Atrophy is the most common magnetic resonance finding in the AIDS dementia complex. More severe grades of deep white matter abnormality are associated with the AIDS dementia complex. Distinguishing progressive multifocal leukoencephalopathy (PML), when extensive, from HIV infection can be problematic.
FIGURE 4–30. Toxoplasmosis. Bilateral high-signal-intensity abnormalities are noted in the basal ganglia on the T2-weighted scan (A). Comparison of pre- (B) and postcontrast (C) T1-weighted scans reveals faint rim enhancement indicative of active disease. Cerebral edema, depicted as high signal intensity on the T2-weighted scan and low signal intensity on the T1-weighted scan, is noted surrounding the larger lesion, specifically extending beyond the thin rim of enhancement defined on the postcontrast scan. The presence of multiple nodular or ring-enhancing basal ganglia (or gray-white matter junction) lesions in the immunocompromised patient suggests the diagnosis of toxoplasmosis, which is the most common intracranial opportunistic infection in AIDS. Other considerations include metastatic disease and lymphoma.

FIGURE 4–31. Progressive multifocal leukoencephalopathy (PML). A small focal area of abnormal high-signal-intensity white matter (arrow) is noted in the left frontal lobe on the T2-weighted scan (A). B, The precontrast T1-weighted scan reveals subtle abnormal low signal intensity in the corresponding region. There is no abnormal enhancement on the postcontrast T1-weighted scan (C). Focal areas of abnormal white matter with high signal intensity on T2-weighted scans, often in an asymmetric distribution, are characteristic of PML. Lesions most often involve the periventricular and subcortical white matter in the parieto-occipital or frontal lobes.
The result is a focal or diffuse encephalitis. Scattered intracranial calcifications and atrophy are seen in chronic disease. Toxoplasmosis is also the most common intracranial opportunistic infection in AIDS. The disease can be due to reactivation of latent infection or fulminant acquired infection. Toxoplasmosis lesions in the brain demonstrate nodular or ring enhancement postcontrast on T1-weighted scans, with surrounding cerebral edema clearly depicted on T2-weighted scans (Fig. 4-30). A common presentation is that of multiple small lesions smaller than 2 cm in diameter. Common locations include the basal ganglia and gray-white matter junction in the cerebral hemispheres. Lymphoma in AIDS, in distinction, is often a single lesion larger than 3 cm in diameter. Central necrosis, with irregular rim enhancement, is also not uncommon in lymphoma in the immunocompromised patient.

Progressive multifocal leukoencephalopathy is a viral demyelinating disease seen in immunocompromised patients, in particular AIDS. Disease progression is rapid; death occurs by 6 months in many cases. On MRI, focal areas of abnormal white matter are seen with high signal intensity on T2-weighted scans. Involvement is often asymmetric (comparing the two hemispheres) and distant from the ventricular system (Fig. 4-31). Lesions may be at first round or oval. These subsequently enlarge, becoming confluent. Mass effect is minimal or absent. There can be both cerebral and cerebellar (Fig. 4-32) involvement.